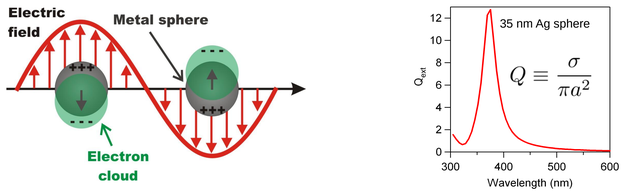
Camden Research Group

Department of Chemistry and Biochemistry, University of Notre Dame,
Notre Dame, IN 46556

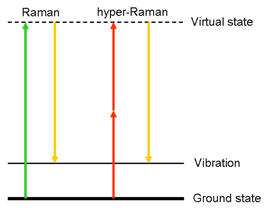
Background

Localized Surface Plasmon Resonance (LSPR): Surface electromagnetic waves that propagate along a metal/dielectric interface, can be viewed as oscillations of the conduction electrons.

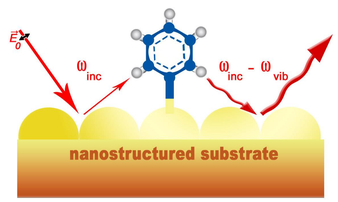


Surface Enhanced Raman Scattering (SERS): Adsorption of a molecule on a metal surface increases the Raman effect by 10^6 – 10^8 making single molecule detection possible.

Surface-Enhanced Hyper-Raman Scattering (SEHRS): Two-photon analog of Raman scattering $w_{HR}=2w_o \pm w_{vib}$



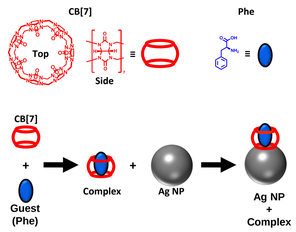
Raman scattering is a type of vibrational spectroscopy.

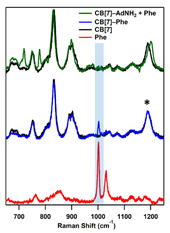


Excitation of the plasmon provides the local field enhancement required for SERS.

Gu, Trujillo, Olson, Camden. *Annu. Rev. Anal. Chem.* **2018**, 11, 13.1-13.23.

SERS Detection with Cucurbit[7]urils



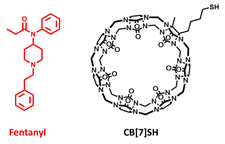


Cucurbit[n]urils (CB[n]s) are a family of barrel-like macrocycles that act as host molecules, binding small molecule "guests" within the cavity.
CB[n]s carbonyl-fringed portals have an affinity for noble metal surfaces, making them advantageous as capture agents for SERS analyte detection platforms – including detection of molecules which have no natural surface seeking functional groups.

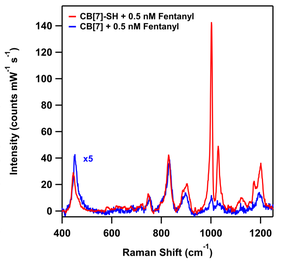
Olson, Braegelman, Zou, Webber, Camden. *Appl. Spectrosc.* **2020**, 74, 11, 1374-1383.

ILLICIT DRUG DETECTION

CB[7] has a high binding affinity for fentanyl relative to many other drugs of abuse (cocaine, heroin, etc), allowing selective capture of fentanyl in mixed samples. A thiolated analog of CB[7] (**CB[7]-SH**) shows potential for sensitive and selective detection of fentanyl due to the open portals while still having a surface seeking thiol group.



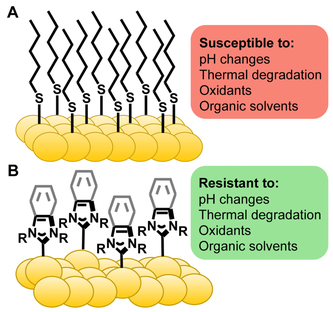
(Right) The capture of fentanyl in CB[7]-SH dramatically improves its detection, as indicated by its characteristic peak (~1000 cm^{-1}). This yields a LOD of fentanyl of 0.37 nM, which is several orders of magnitude better than previous literature values.



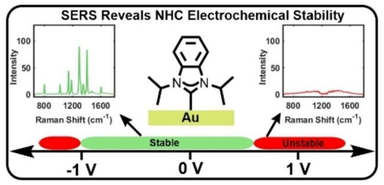
While SERS is exceptionally good at detecting small concentrations of fentanyl (< 0.1 ng/mL), analysis of mixed samples is complicated by the complex nature of non-specific analyte binding to AgNPs. CB[7]SH is able to selectively capture fentanyl, according to NMR binding studies, but is not able to form dense enough monolayers on AgNPs to prevent fentanyl from binding directly to the surface itself.

Braegelman, Thimes, Sherman, Addonizio, Lieberman, Camden, Webber. *ACS Appl. Nano Mater.* **2024,** Submitted.

Breaking the Thiol Barrier

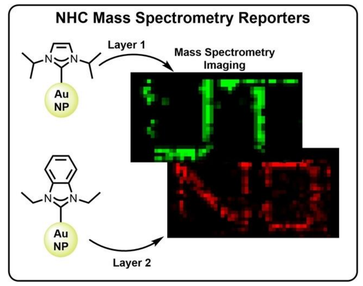


Camden and Jenkins recently developed a benchtop method to append N-heterocyclic carbene (NHC) monolayers to citrate-capped gold nanoparticles (AuNPs). The resulting monolayers have displayed superior resistance, compared to the traditional thiol-based monolayers, when subjected to chemical, thermal, and biological stressors.



NHC monolayers are also stable under continuous voltametric cycling, but degrade at extreme voltages and extensive cycling.

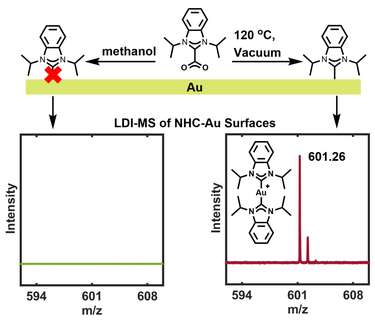
Kaur, Thimes, Camden, Jenkins, *Chem. Commun.* **2022**, 58, 13188-13197.
Dominique, Chandran, Jensen, Jenkins, Camden. *Chem. Eur. J.* **2024**, e202303681.



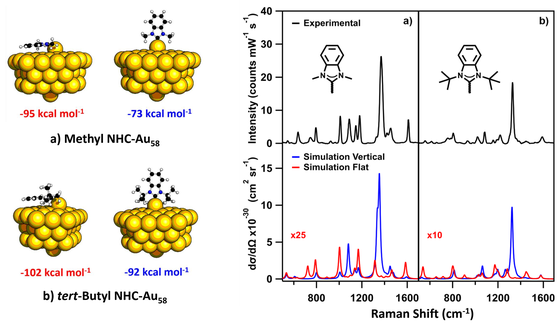
Dominique, Jensen, Kaur, Kotseos, Boggess, Jenkins, Camden. *Angew. Chem. Int. Ed.* **2023**, 62, e202219182.

NHC-functionalized AuNPs are highly tunable and bright mass spectrometry reporters. NHC ligands fragment less and achieve higher ion yield than conventional thiol systems which enables bioconjugation monitoring, mass spectrometry imaging, and data storage applications. Critical for these NHC-based applications are the NHC functional groups, which determine, to a great extent, the monolayer properties.
(**Above**) The unique ion for each NHC-AuNP can be utilized to encode messages or enable multiplexed imaging for mass spectrometry.
(**Below**) The strong bond between the NHC and Au surface enables multiple-step post-synthetic modification of their functional groups for desirable applications.

Deposition protocol matters (Right). NHCs form self-assembled monolayers when deposited on Au. A systematic comparison of various widely used deposition protocols has been done. The results show that the fundamental characteristics of the Au-NHC monolayer is heavily dependent on the deposition protocol. The LDI-MS spectra show the vacuum deposition results in a chemisorbed monolayer.

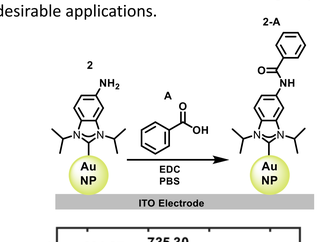


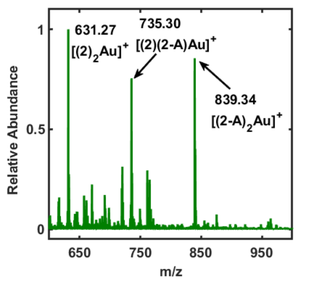
Chandran, Dominique, Ekowo, Kaur, Jensen, Jenkins, Camden. **2024**, Submitted.



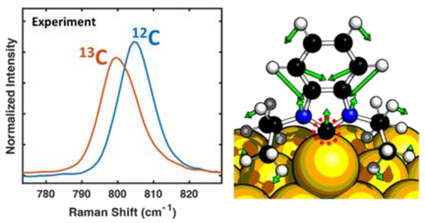
Thimes, Santos, Chen, Kaur, Jensen, Jenkins, Camden. *J. Phys. Chem. Lett.* **2023,** 14, 4219-4224.

NHC Orientation (Above). SERS is uniquely positioned to address questions related to molecular orientation as the intensity of spectral bands are dictated by surface selection rules. Simulations of the most favorable binding configurations of a single NHC ligand on a Au_{58} cluster revealed that the flat configuration is the most stable. Comparison of the experimental SERS results with the theoretically calculated spectra for flat and vertical configurations of methyl NHC-AuNPs (**a**) and *tert*-butyl NHC-AuNPs (**b**) show the simultaneous detection of both NHC configurations on the surface. In agreement with previous literature, the methyl NHC adopts a primarily flat configuration; surprisingly, the bulkier tert-butyl NHC also adopts a primarily flat configuration.



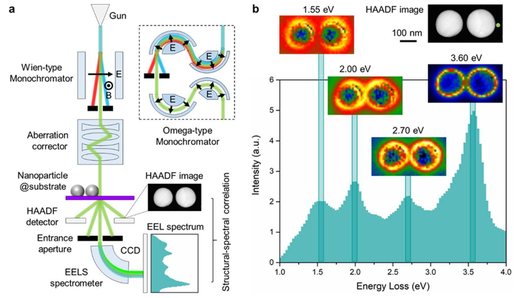


Elucidating the Au-C stretch in NHC on AuNP (Below). Isotopically labeled C (red circle) allows assignment of the SERS spectrum (left) and normal modes (right) with significant Au-C character.



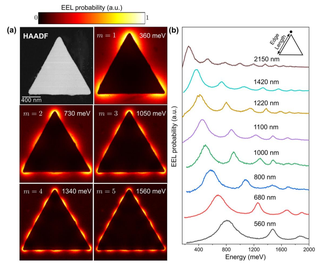
Jensen, Chowdhury, Hu, Jensen, Camden, Jenkins. *Chem. Commun.* **2023**, 59, 14524-14527.

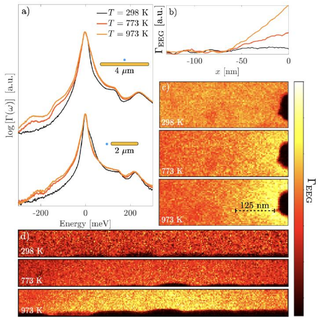
STEM-EELS



A scanning transmission electron microscope (STEM) can probe localized surface plasmons with nanometer spatial resolution and ultra-high energy resolution using electron energy loss spectroscopy (EELS).

Using the world class electron microscope available to us at Oak Ridge National Laboratory, we have recently characterized the near-field response of individual gold nanotriangles (NT) over a broad, visible-to-infrared spectral region. EEL spectrum images for a 1420 nm gold NT displaying the spatial profiles of its *m=1-7* Fabry-Pérot modes (a), and the EEL spectra of a set of gold NTs vs edge length (b) is shown on the right.



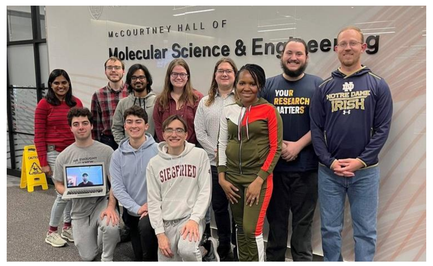


In our latest work, we studied the localization of low-grade heat using Au nanowires on a SiN substrate supporting thermally active Fabry-Pérot (FP) resonances. Temperature dependent and spatially resolved EEG spectrum images obtained at *l=1* FP mode energy at the end of the wire (c), and spectrum images obtained at *l=2* FP mode energy near the center of the wire (d) are shown on the right, along with the EEL and EEG point spectra of two wires at different temperatures.

Wu, Li, Camden. *Chem. Rev.* **2018,** 118, 2994-3031.
Kumar, Rossi, Lawson, Neal, Hachtel, Neretina, Masiello, Camden. *J. Phys. Chem. C.* **2023,** 127, 14, 6777–6784.
Beutler, Kumar, Duddy, Bourgeois, Srijanto, Hachtel, Masiello, Camden. *ACS Energy Lett.* **2024,** accepted.

Acknowledgements

ORISE
BERTHIAUME INSTITUTE FOR PRECISION HEALTH
ND Energy CENTER FOR SUSTAINABLE ENERGY AT NOTRE DAME
CBM Center for Bioanalytic Metrology
ALS
NSF



Collaborators
University of Notre Dame
The Lieberman Lab
The Neretina Lab
The Smith Lab
The Svarovsky Lab
The Webber Lab
University of Tennessee
The Jenkins Lab
The Rack Lab
Pennsylvania State University
The Jensen Lab
Johns Hopkins University
The Arroyo Lab
University of Washington
The Masiello Lab
Oak Ridge National Laboratory
Dr. Jordan A Hachtel
Lawrence-Berkeley National Laboratory
Dr. Hans Bechtel